A hybrid technique to solve MCDA problems in a UK National Health Service Trust

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Abstract
This paper reports on research that compared two multiple criteria decision analysis (MCDA) models: Analytical Hierarchy Process (AHP) and Evidential Reasoning (ER). It discusses the development of a hybrid version, specifically designed to select and justify the location for a future urban healthcare infrastructure within a UK based National Health Service (NHS) Trust. We recommend the use of a hybrid model using aspects of AHP at the criteria level and aspects of ER at the sub-criteria level. We suggest using ER with pair-wise comparison elements as the most effective solution.

Keywords: MCDA, AHP, Site selection

Introduction
The hierarchical structure of the model was first built in partnership with the main NHS decision makers, multiple professional stakeholders, and members of the public. Along with the consultation process the purpose was to build a consensus on the instrument used to inform the final infrastructure site selection decision. This accepted model encompassed seven criteria and 28 sub-criteria. The rationale for using MCDA to inform the site location was increase the transparency and the robustness of the decision making process, which had become an increasing concern for the local healthcare Trusts. The NHS decision makers had to be able to justify the outcome confidently to the large range of stakeholders, and the very vocal and engaged members of the public (Darzi Report, 2007; DoH, 2010). For these reasons, the first attempt applied the MCDA model using the Evidential Reasoning (ER) approach. The ER method enabled the development of weighting and assessment criteria and sub-criteria. It identified which alternatives were most logically suitable. In order to build confidence into the results, sensitivity analysis was conducted. This helped to gain a deeper insight into the results and to appreciate aspects of uncertainty within the decision (Dehe et al, 2011). In parallel with the development of the ER model, the Analytical Hierarchy Process (AHP) was utilised to compare the process and the results. AHP is one of the most popular MCDA techniques (Saaty, 1980). In this paper we conclude that a hybrid model can be developed using elements of ER and AHP in order to optimise both the process and the actual results.

Literature review

Model definition

Ackoff and Sasieni (1968) defined a model as a representation of the reality. Pidd (2003) explained this simplistic definition did not address several aspects such as the reason why a model is required and built, the fact that people have different worldview and perception of the reality, as well as that a model can never be entirely complete and accurate. Therefore, Pidd (2003) preferred defining a model as an external and explicit representation part of a reality as seen by the decision makers and modellers. This means, models are an approximation of the reality and that according to the specific model used to look at the real world problem the processes or outcomes might be different. In this paper the authors intend to establish, whether by looking at the same real world problem - the site location for a new healthcare centre - throughout two different MCDA models: ER and AHP, the process and the outcomes are different. In order to do so, an evaluation framework was developed.

Model evaluation

Box and Draper (1987, p.424) explained that "essentially, all models are wrong, but some are more useful than other". Hence, it can be established that models have different characteristics, and one may want to identify the most appropriate model to use for solving a specific problem in an identified environment. Our MCDA models support the decision making process and alternatives assessment. Therefore, to identify the most appropriate model, one may want to look at: i) the robustness and the representativeness of the results generated, measures of accuracy; and ii) the repeatability and the reproducibility, associated with the consistency and transparency, measures of precision of the model and its process (Breyfogle, 2003). Hence, to evaluate the process, the consistency and transparency will be examined; for instance, will the models allow the decision makers and participants to be consistent at different time, based on consensus? Figure 1 illustrates an MCDA assessment framework used to determine which model would be optimum for this healthcare organisation while selecting future healthcare centre location.

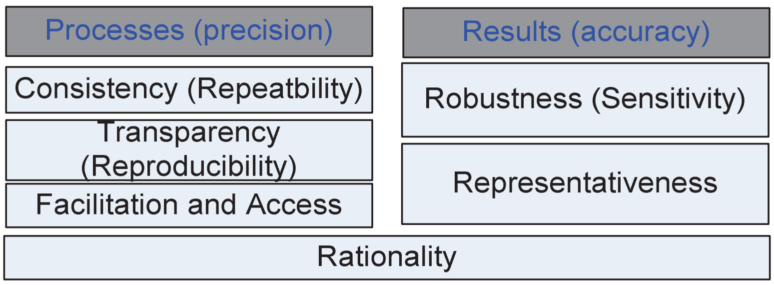

Figure 1 - A compiled framework for MCDA Comparison (adapted from Breyfogle, 2003)

Multiple Criteria Decision Analysis MCDA

Ram et al., (2011) and Golmohammadi and Mellat-Parast (2012) stated that when strategic options are being evaluated for instance in supplier selection, MCDA is the suitable approach to handle conflicting and both qualitative and quantitative objectives. MCDA provides a framework to aid with making complex decision by creating a platform where all stakeholders can share information, in order to develop a consensus or find a compromise. Tavana and Sodenkamp (2010) explained that MCDA enables the stakeholders to create a framework to exchange their information and knowledge while exploring their value systems through the weighting and scoring mechanisms. Furthermore, Ormerod (2010) suggested that different frameworks and mechanisms inform the stakeholders' beliefs about the relationship between the options and the outcomes. While, Belton and Stuart (2002) explained the myths of MCDA, emphasising that there are no right answers due to the subjectivity of the inputs. The subjectivity is inherent to the choice of criteria, the weighting and the assessment; therefore according to the framework selected the subjectivity might be different, even with a common final aim to tend toward a transparent, informed and sensitive decision to healthcare site selection in this instance.

MCDA in site selection

Site selection is a critically strategic decision as it could potentially make or break a business, independently of the industry because location decisions involve long term resource commitment and have significant impacts on the operations strategy and the key operations performance indicators such as cost, flexibility, speed and dependability (Yang, Lee, 1997; Ertuğrul, Karakaşoğlu, 2008). The literature is very diverse regarding site selection or facility location. However, limited case studies investigate healthcare site selection problem using MCDA. We have only identified that Vahidnia et al., (2009) developed in their paper, an AHP model to find the best site for a new hospital. Their model has five criteria: distance from arterial routes, travel time, contamination, land cost and population density.

Analytical Hierarchy Process AHP

AHP is a general theory of measurement; it is an effective approach to handling decision making and certainly the most popular MCDA methodology (Bozbura, Beskese, & Kahraman, 2007; Kang & Lee, 2007; Partovi, 2007). It was developed by Saaty in the 1980's for resolving unstructured problems in any disciples or business areas (Wu et al, 2007). Saaty and Vargas (2001) explained that it was designed to cope with the rational and the intuitive to optimise the evaluation of the number of alternatives available. By undertaking pair-wise comparison judgments and aggregating the scores, a ranking of alternative is developed. The advantage resides in the fact that it allows inconsistency to be assessed but simultaneously improving the consistency of the decision (Saaty and Vargas, 2001). Chin, Xu, Yang, Lam, (2008) recognised the excellence of the AHP approach, however, explained its two limitations: firstly, as AHP treats criteria weights and scores in the same way applying pair-wise comparison, which they believed, leads to ranking reversal problems; and secondly, its lack of capacity in coping with uncertainty.

Evidential Reasoning ER

The ER approach is amongst the latest MCDA technique, developed to handle uncertainty and randomness. Xu (2011), Liu, Bian, Lin, Dong and Xu (2011) and Wang and Elhag (2008) stated that the ER was first developed in 1994 by Yang and Singh to solve multiple criteria decision problems taking into account qualitative and quantitative attributes as well as the inherent uncertainty, by combining the Dempster–Shaffer (DS) theory (Shafer, 1976) with a distributed modelling framework. The difference with the other more traditional MCDA models is that ER uses an extended decision matrix in which each attribute of an alternative is described by a distributed assessment using a belief structure (Xu, Yang 2003; Liu et al., 2011). For instance the distributed assessment results of the sub-criteria regeneration impact for alternative A can be {(Best, 33%), (Good, 33%), (Average, 33%), (Poor, 0%), (Worst, 0%)}, whereas for B it can be {(Best, 0%), (Good, 50%), (Average, 50%), (Poor, 0%), (Worst, 0%)}. ER uses a Simple Additive Weighting as scoring methods to calculate the overall score of an alternative as the weighted sum of the attribute scores or utilities (Yang, 2001; Xu, Yang, 2003, Xu, 2011).

Model comparison

Ertuğrul, Karakaşoğlu, (2008) contrasted two modelling techniques AHP and TOPSIS and they concluded that, despite that both AHP and TOPSIS have their own characteristics, the ranking of the three alternatives were the same. They demonstrated that when the decision makers were consistent both methods could be appropriate; even if, they recognised that decision makers should choose the methods fitting the problems and the situation.

To structure our research and the presentation of this paper, an explicit research question was developed: Are the processes and outcomes significantly different according to the models ER or AHP implemention?

Methodology

During the facilitated workshops, which involved a total of 45 stakeholders, it was possible to compile both final ER and AHP models with their associated weightings. The methods used to collect the data were group discussions, brainstorming and focus groups. The authors considered but rejected using a questionnaire to capture and interpret the data – the methods chosen satisfied both the transparency and establishment of a consensus between the stakeholders.

The rationale for comparing the two models was based on the following assumptions by the authors: i) all models are wrong, but some are more useful than other (Box and Draper, 1987), the authors wanted to establish whether one of the models was more useful than the other; ii) decision makers might feel more confident using one or the other of the models; and iii) to identify whether the two models were going to lead to different decision making outcomes.

To enable the comparison the authors looked at: i) the robustness and the representativeness of the results generated, which are measures of accuracy; and ii) the repeatability and reproducibility associated with the consistency and transparency; these are measures of precision of the models applied (Breyfogle, 2003). These objectives led to explore if the processes and outcomes are significantly different according to the model implemented.

Findings

The AHP model

It has traditionally three levels: the goal, the criteria and the alternatives as illustrated in Figure 2. The set of the seven criteria is the common structure, as it is independent of the selected modelling techniques. In the AHP model, the weightings of criteria are pair-wise compared and the results are shown in Table 1 below. This was established by the group of decision makers, and is consistent with the weighting determined in the ER model.

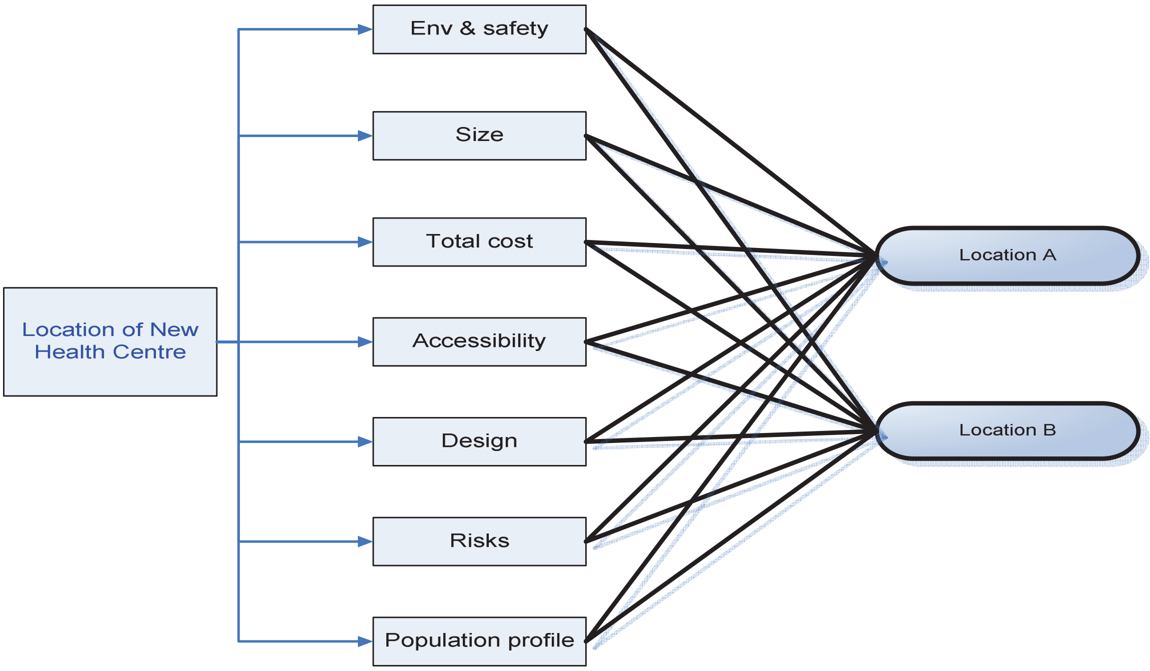

Figure 2 - AHP model structure

Table 1 - Criteria pair-wise comparison table

Criteria	*Env & Safety*	*Size*	*Total cost*	*Accessibility*	*Design*	*Risks*	*Pop profile*
Env & Safety	1	1/3	1/7	1/7	1/3	1/3	1
Size	3	1	1/5	1/5	1	1	3
Total cost	7	5	1	3	5	5	7
Accessibility	7	5	1/3	1	5	5	7
Design	3	1	1/5	1/5	1	1	3
Risks	3	1	1/5	1/5	1	1	3
Pop profile	1	1/3	1/7	1/7	1/3	1/3	1
Sum	25	13.667	2.219	4.886	13.667	13.667	25
Weights (%)	**3.53**	**8.44**	**38.89**	**28.75**	**8.44**	**8.44**	**3.53**

The ER model

From the facilitated workshops, which involved a total of 45 stakeholders, it was possible to compile the final model with the associated weightings as shown in Figure 3 below. This model is composed of seven criteria and 28 sub-criteria. In the ER approach the assessment takes place at the sub-criteria level, therefore, it was required to identify whether the sub-criteria are evaluated quantitatively (noted Q) or qualitatively (noted QL). Once the weightings were identified and validated they were normalized, which are used later in this analysis.

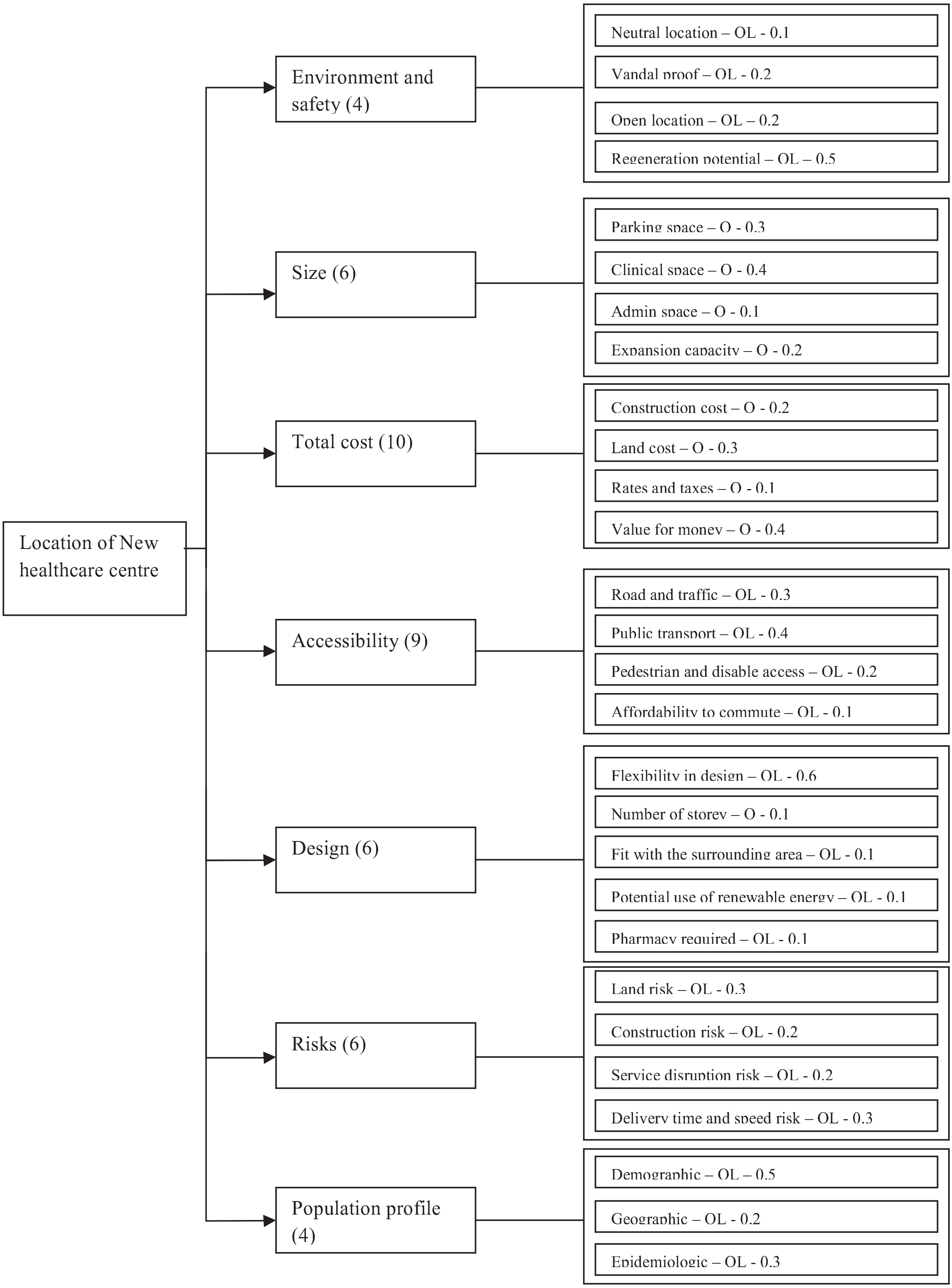

Figure 3 - ER model structure - criteria and sub-criteria weightings (Dehe, et al., 2011)

In Table 2 below, the weighting assigned for both models are presented. Note that the weighting range is different whether ER or AHP was the selected framework to solve the problem. With ER the weightings are included in a range from 8.90% to 22.22%; whereas with AHP the range is wider from 3.53% to 38.89%. From the assessment it was established that when stakeholders use a Likert scale from 1 to 10 it is likely that little difference can be perceived between the criteria but that the uniformity is respected and it is highly transparent. However, using pair-wise comparison, the difference is amplified, but there is room for inconsistency when criteria are being compared against other criteria, and stakeholders might have a less transparent perception of the weighting phase. The second relevant point to mention is that in this case using ER or AHP led to the same ranking, which is positive, and translate that the decision makers were consistent in their approach, and gave confidence to proceed with the comparison.

Table 2 - Criteria weightings and rankings comparison

	ER		***AHP***	
Criteria	***Weight (%)***	***Rank***	***Weight (%)***	***Rank***
Environment & Safety	8.9	6	3.53	6
Size	13.33	3	8.44	3
Total Cost	22.22	1	38.89	1
Accessibility	20	2	28.75	2
Design	13.33	3	8.44	3
Risks	13.33	3	8.44	3
Population Profile	8.9	6	3.53	6

ER and AHP the Assessments

The next step was the assessment of alternatives: A and B in this case; which allowed the ranking of the alternatives. With ER the degree of belief for each sub-criteria is established independently, whereas AHP remains at the criteria level and assessed the alternative against each other using the pair-wise comparison. Table 3 compiled the results from both assessments at the criteria level; note that even if the results provided shows that location A is significantly the preferred option in 3 criteria, and location B in 2 criteria, and that overall A is the preferred option, the quantification differences which is the most paramount indicator for the final decision is substantially different according the selected modelling approach. Therefore, for this reason we undertook a statistical test: Two-Proportion Test. Hypothesis testing: is there any significant difference between the results scoring range of ER and AHP?

> H0: proportion [ER(a-b) = AHP(a-b)] – there are no differences between the proportions.
> H1: proportion [ER(a-b) $\neq$ AHP(a-b)] – there are differences between the proportions.
> P value = 0 <0.05 (with $\alpha = 0.05$). H1 can be accepted, we can be 95% confident that there is a difference between the results from ER and AHP.

With ER it is suggested that both alternatives reach similar scores (A=56 and B=54 or normalised A=51 and B=49), it can be interpreted as location A and B are performing similarly; however, using the AHP model, there is less doubt that alternative A significantly outstrips the alternative B (A=62.35 and B=37.65 normalised). Having said that, this does not indicate which model provides the optimum solution in this example and in this context.

Table 3 - Scoring differences between ER and AHP

	Scoring			
	ER		***AHP***	
Criteria	***A***	***B***	***A***	***B***
Env & Safety	**67**	56	**75**	25
Size	50	**91**	12.5	**87.5**
Total Cost	**66**	34	**87.5**	12.5
Accessibility	45	45	50	50
Design	60	**81**	16.67	**83.33**
Risks	**58**	46	**75**	25
Population Profile	50	50	50	50
AGGREGATE	**56**	54	**62.4**	37.6
Normalised	51	49	62.4	37.6

Therefore, form Table 3, one can wonder if, based on the results, the final recommendations would change depending on the ER or AHP methods? Are both alternatives offering similar attractiveness as the ER results suggest or location A is significantly superior as AHP suggests? And if these results are individually presented to the decision makers effect how will they feel about them?

Discussion

The framework developed from the literature was put together to assess both models and discuss their implications from a practical and managerial perspectives. The 'rationality' element was not considered as a criterion on its own, but rather as an aspect linked to each of the five criteria transversal to both the process and results (Figure 1).

By using ER, the weighting and assessment processes generated good consistency; participants were able to repeat over time their assessment quite confidently by using the Likert scale methodology. However, using AHP and the pair-wise comparison the process was found to be less consistent, especially as the model became more complex, where anomalies and contradiction were created in the model. This was partially explained by the decision makers not being familiar with pair-wise comparison methods. Therefore, it can be suggested that ER was more likely to be consistent for the assessing of alternatives, but could lead to some inconsistency within the weighting process as participants and decision makers were reluctant to use the whole scale and most weightings were only spread between 6 and 9 of the 1 to 10 entire scale, which might affect the final results.

In term of transparency, ER seemed easier for the majority of the participants involved, reinforcing the comments from Xu (2011) that ER is a 'simple' process, also there are many different ways to compile and aggregate the results. The pair-wise comparison had to be established by a consensus, and some people found it slightly confusing and rather redundant, which did not increase the transparency factor. Moreover, AHP did not allow keeping track of what happened during the assessment process.

On the other hand, the results robustness was hampered by the possibility of introducing bias; the stability of the models and the sensibility aspect of the results were also factors. Ideally the model needs to be bias proof and sensible enough to translate the results adequately. We observed that AHP was potentially more sensible as the spread shown in our example (a larger difference) but more likely to introduce a bias in the results by finding consensus based on the strongest personality in the room while weighting and assessing criteria and alternatives. Moreover, the AHP method could possibly introduce unsteady elements by not following a logical and consistent pair-wise assessment and contradictions might be input into the model. We felt that ER was less subject to bias and was slightly more stable than AHP, perhaps because it works at the lower level of the model.

Conclusion

It was established that using ER or AHP led to the same solutions: the location A was in both cases the preferred option. However, the differences between the alternatives were significant and could impact the interpretation of the results. As the processes alter according to the model selected one needs to consider the practical and managerial implications for selecting one or the other.

It was found that by using ER the weightings were more consistent than when the pair-wise comparison of AHP was used at the sub-criteria level; however, it was more consistent at the criteria level. In terms of transparency and to reach a consensus, it was established that ER appeared easier to grasp for the majority of the participants involved than the pair-wise comparison. Furthermore, ER allowed tracking of the evolution of the decision making processes, something that AHP could not easily facilitate.

Regarding the results and accuracy, it was noticed that AHP was potentially more sensitive but likely to allow bias in the results during the weighting and assessment of the criteria and alternatives. It was felt that ER was less subject to bias and slightly more 'stable' than AHP.

The authors recognise the benefits of AHP and ER and identified the two models as complementary; it will be recommended, in this particular case, to use a hybrid model using aspects of AHP at the criteria level and aspects of ER at the sub-criteria level. Therefore, it is argued that to achieve the optimum, the most transparent and robust decision, using ER with some pair-wise comparison elements would be the most effective solution for the Trust. However, this could be rather resource intensive. The paper makes a contribution by exploring the different implications for decision makers in applying ER or AHP to identify the optimum location for future healthcare infrastructure.

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